DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 345—B

GROUND WATER FOR IRRIGATION IN THE VICINITY OF ENID, OKLAHOMA

BY

A. T. SCHWENNESEN

WITH A NOTE ON

GROUND WATER FOR IRRIGATION ON THE GREAT PLAINS

BY O. E. MEINZER

Contributions to the Hydrology of the United States, 1914—B

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GROUND WATER FOR IRRIGATION IN THE VICINITY OF ENID, OKLAHOMA.

By A. T. Schwennesen.

INTRODUCTION.

Enid, the county seat of Garfield County, Okla., is situated in the north-central part of the State, in the Cimarron River drainage basin, near the divide between this basin and that of the Salt Fork of the Arkansas. The region has the gently undulating surface characteristic of much of the western prairie country.

In 1910 Enid had a population of 13,799. It is the center of a prosperous farming community and is favored with excellent railroad facilities. The principal crops in this vicinity are wheat, Indian corn, Kafir corn, and Milo maize. Potatoes, peanuts, melons, apples, garden truck, and small fruits are also raised.

The average annual precipitation at Enid for the nine years prior to 1913 was 32.48 inches. During the season of 1912–13 this region was affected by the drought that prevailed throughout the West and Middle West and the rainfall was only 18.28 inches. This condition naturally suggested the idea of supplying the deficiency in rainfall by artificial means. As no surface water seemed to be available for this purpose, knowledge of what had been accomplished in other parts of the West by the utilization of ground water for irrigation directed attention to this as a possible source. As ideas of the quantity and occurrence of the available ground-water supply were rather vague, it was thought desirable to obtain some reliable data as to the extent and character of the water-bearing beds before extensive pumping irrigation was advocated. Correspondence was therefore entered into with the United States Geological Survey, urging that a ground-water survey of the region be made. Unfortunately circumstances would not permit the making of a complete survey at this time, and the writer, to whom the investigation was assigned, was able to spend only a few days in the field. In the preparation of this report Water-Supply Paper 148, entitled "Geology and water resources of Oklahoma," by C. N. Gould, was freely consulted. The data in regard to pumping tests at Oklahoma City have been taken from the report of Hiram Phillips, John W. Alvord, and J. W. Billingsley, members of the board of engineers engaged to plan a water-supply system for that city.

GEOLOGIC OUTLINE.

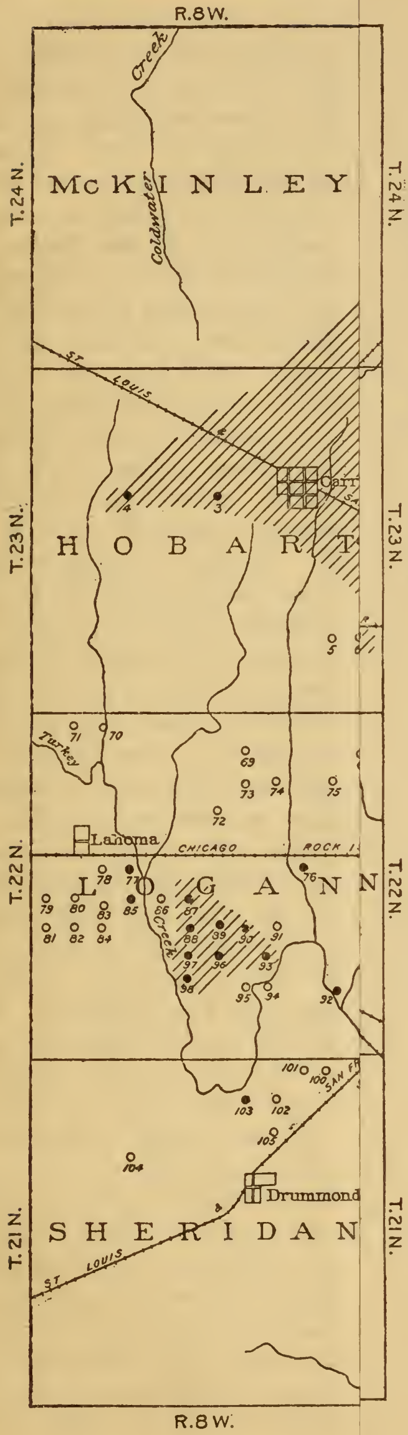
Rocks of Carboniferous age, known as the "Red Beds," cover large areas in central and western Oklahoma. They consist principally of brick-red shales locally called "red keel" but include some thin layers of interbedded sandstones. They dip 10 to 20 feet to the mile toward the west and southwest and are shown by deep-well sections to be of great thickness. A well which is being drilled by the city of Enid 2 miles north of town, in the NW. ¼ sec. 29, North Enid Township, penetrated over 2,000 feet of red shale, and two wells drilled at El Reno, Canadian County, Okla., 60 miles south of Enid, were in the "Red Beds" for 1,700 and 3,300 feet, respectively.

In some parts of the State the "Red Beds" are covered by a thin blanket of unconsolidated clays, sands, and gravels, which are geologically much younger and probably belong to the Tertiary system. These deposits occur in the region about Enid, covering the area approximately shown by the shading on Plate I. At one time Tertiary deposits of this kind probably covered the entire western part of the State, but much of this material has been removed by erosion, and in central Oklahoma remnants are left only on some of the interstream areas. Even in these areas streams have worn through the Tertiary deposits into the underlying "Red Beds," as along Skeleton Creek just south of Enid, where the "Red Beds" are exposed across the whole width of the valley. In some places these valleys have been partly refilled by stream deposits, as along Turkey Creek 7 miles southwest of Enid.

The Tertiary deposits in the vicinity of Enid range from a thin layer to beds 60 feet thick. In wells sunk into these deposits three classes of material can generally be distinguished—first, a layer of soil, varying in different localities from sand to heavy clay or "gumbo," depending upon the character of the underlying material from which it has been derived; second, a layer of yellow, reddish, or bluish clay, more or less sandy in different places and grading into the overlying soil; and third, material composed of well-rounded quartz fragments, varying from quicksand to fine gravel, usually coarsest near the bottom. Underlying this is the red shale, or "keel," which forms the bedrock in this whole region.

WATER IN THE CARBONIFEROUS "RED BEDS."

In the agricultural district around Enid many of the domestic wells derive water from the "Red Beds." These red-bed wells are all shallow and tap the water-bearing sandstones interbedded with the predominating red shale. In most places one or more water-bearing sandstone beds may be reached by drilling less than 100 feet, but the driller of the deep municipal test well north of Enid reported that below the first 48 feet of Tertiary deposits, of which 20 feet was soil



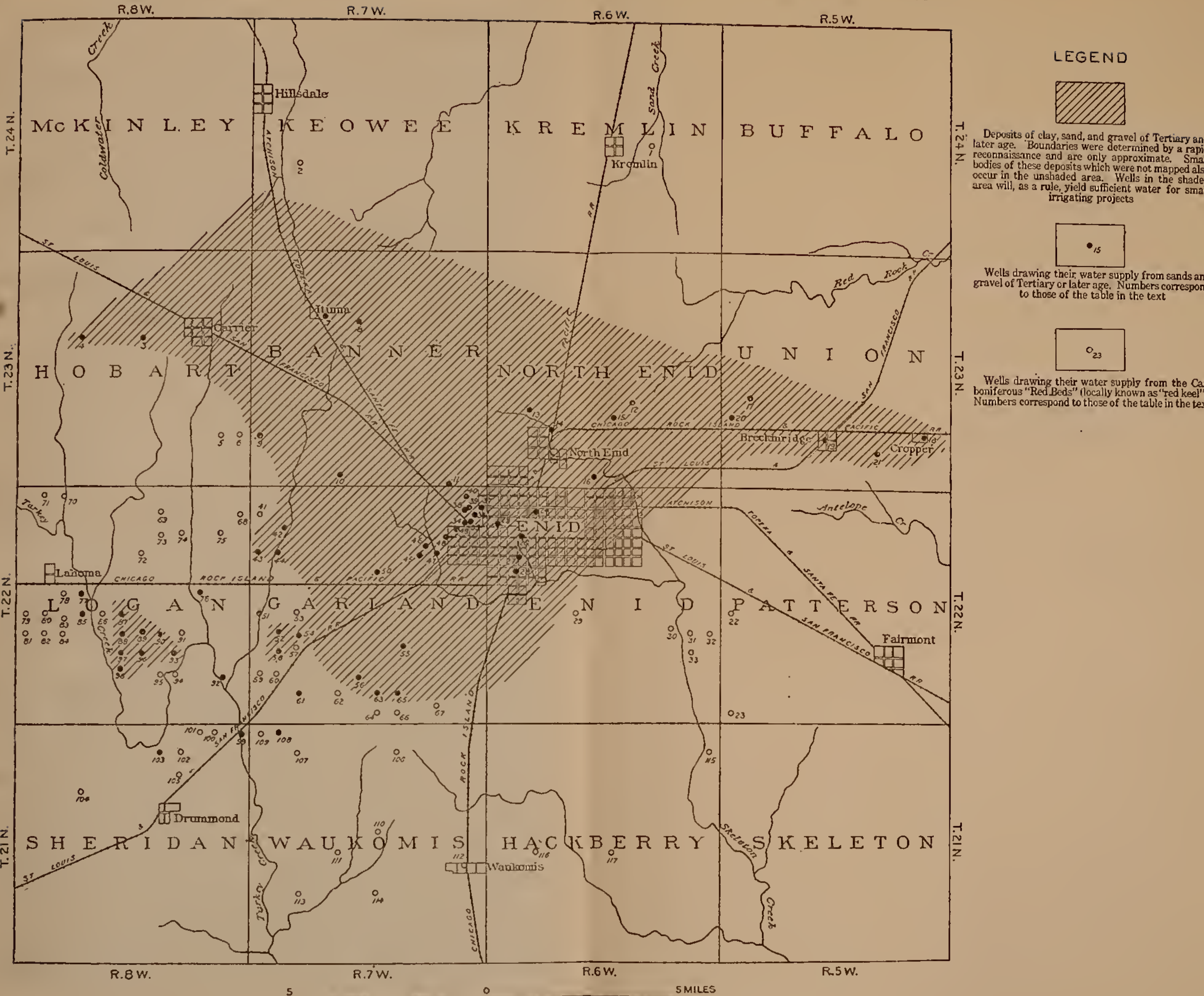
LEGEND

Deposits of clay, sand, and gravel of Tertiary and later age. Boundaries were determined by a rapid reconnaissance and are only approximate. Small bodies of these deposits which were not mapped also occur in the unshaded area. Wells in the shaded area will, as a rule, yield sufficient water for small irrigating projects

Wells drawing their water supply from sands and gravel of Tertiary or later age. Numbers correspond to those of the table in the text

Wells drawing their water supply from the Carboniferous "Red Beds" (locally known as "red keel"). Numbers correspond to those of the table in the text

MAP OF T



MAP OF THE VICINITY OF ENID, OKLA., SHOWING GROUND-WATER CONDITIONS.

and 28 feet coarse water-bearing sand, no more water-bearing beds were found in a total thickness of more than 2,000 feet of red shale. At a depth of 2,145 feet the drill penetrated a thin bed of red sandstone containing salt water, below which 30 feet of "limestone" was reported. Deep borings in other parts of the country show that the sandstone beds are lenticular and not continuous for any considerable distance, so that a water-bearing bed which is present in one well may be entirely lacking in another well not far away. For this reason the scarcity of water-bearing beds shown by the Enid well log must not be taken as representative of the whole region, and in the average well the conditions will usually be better. Several shallow bored wells in the "Red Beds" along Skeleton Creek south of town flow at certain times of the year. The occurrence is not of economic importance but nevertheless is of considerable interest. The discharge from these wells is small and with one exception they flow only during the rainy season. One well on the farm of J. A. Henry, in the SE. ¼ sec. 1, Hackberry Township, flows continuously at the rate of about 8 gallons a minute. The well is 40 feet deep and the water rises in the casing 3½ feet above the ground. The strong taste and the white crust that it forms on evaporation show that this water is heavily charged with mineral matter. The shallow depth of the wells, the low artesian head, and the coincidence of the period of flow with the rainy season show that the source of the artesian water is not very far away. As the prevailing dip of the rocks is toward the southwest, the porous bed tapped by the wells probably appears at the surface somewhere at a higher elevation not far northeast and obtains its supply solely from rain that percolates into the outcrop.

No data are available on the maximum yield to be expected from wells in the "Red Beds" in this particular region, but some pumping tests made at Oklahoma City, 75 miles south of Enid, by the board of engineers employed to plan a water system for that city, are instructive. Pumping tests were made on 14 of the largest and most productive wells in or near Oklahoma City. They are bored wells, 6 to 10 inches in diameter and 217 to 256 feet deep. The greatest recorded yield from any of them was 175 gallons a minute in a continuous 24-hour test. Before the test the water level stood 47 feet below the top of the casing and during the greater part of the test 180 feet below, showing a drawdown of 133 feet. The well therefore yielded about 1.3 gallons a minute for each foot of drawdown. The greatest yield per foot of drawdown from the wells tested was 1.8 gallons a minute and the lowest 0.65 gallon. This shows that the depth from which the water must be lifted and consequently the unit cost of the water increases very rapidly with the duty demanded of the wells.

Analyses of red-bed waters from different parts of the State show great differences in the amounts of dissolved mineral matter, even

where the samples were taken from wells very near each other. Gould makes a comparison of analyses of water from eight red-bed wells located within a radius of two blocks in the city of Norman, which he considers typical of wells supplied from the "Red Beds."[1] In these waters the total dissolved solids range from 572 to 4,365 parts per million and there is a corresponding range in the quantities of the various salts. The fact that the wells were all shallow, ranging in depth from 23 to 50 feet, and drew their supplies from rocks at the same geologic horizon makes the great variation in quality of water all the more remarkable. The more highly mineralized red-bed waters are unsatisfactory for irrigation, but many of the waters from the "Red Beds" can be used without injury to plant growth. More highly mineralized water can safely be used in the vicinity of Enid than in regions that are less well drained and receive less precipitation. Water that does not have a salty taste will usually be found safe for irrigation.

WATER IN THE TERTIARY AND LATER DEPOSITS.

Practically all the water used for domestic and industrial supplies in Enid is obtained from wells sunk in the Tertiary sands and gravels overlying the "red keel." These sands and gravels differ in thickness at different places, but they seem to be fairly continuous and a boring seldom fails to find them.

Dug, bored, and driven wells are commonly used. Most of the bored and driven wells are sunk to the "red keel" and their casings are perforated at the water stratum. Where large amounts of water are used a system of several driven wells connected to a common suction main has usually been found most satisfactory. Some single wells, however, produce large yields; the large dug well of the Atchison, Topeka & Santa Fe Railway Co. supplies many locomotives daily, and the combination dug and bored well on the ranch of Charles King, 2 miles southwest of the city, furnishes plenty of water for irrigation.

The largest pumping plant in Enid using driven wells is at the city waterworks. Considerable forethought was exercised in planning this well system. Before a site for the plant was chosen 10 test wells were put down to the "red keel" to determine the thickness and character of the water-bearing beds. The line of wells was about 2 miles long and extended northeastward from the center of the SE. ¼ sec. 11, Garland Township. Several test wells were then bored 25 feet apart where the water-bearing sands were found to be thickest. One of these wells was pumped continuously to capacity for 48 hours and the drawdown in it and the other wells was noted. As the water table was not appreciably lowered beyond a radius of 27 feet from

[1] Gould, C. N., Geology and water resources of Oklahoma: U. S. Geol. Survey Water-Supply Paper 148, pp. 142-145, 1905.

the pumped well that distance was adopted as the proper spacing for the wells in the proposed system.

The system which was planned as a result of these experiments and is now in use consists of a circular pump pit with two drifts or "tunnels" extending in opposite directions from the bottom of the pit, with sand points driven from the floor of the drifts through the water-bearing sands to the "red keel." The pit is 28 feet in diameter and 31 feet deep. Each drift is 400 feet long and has sixteen 4-inch drive points 27 feet apart, fitted with Cook screens. The points in each tunnel are connected to a common suction main and fitted with valves so that any one of the points may be cut out. The pumps are operated by steam and have an average daily capacity of 1,000,000 to 1,500,000 gallons. A generalized log of this entire group of wells is given in the table of well records (No. 35).

A similar system used by the Arctic Ice & Refrigerating Co. consists of sixty 2-inch Cook sand points driven to the "red keel" from the bottom of two trenches, each 60 feet long, 12 feet wide, and 16 feet deep, set at right angles to each other. An electrically operated pump on a level with the bottom of the trenches is connected with the wells through a common suction main. This pump is often operated continuously for 24 hours at the rate of 200 gallons a minute without appreciably weakening the supply.

Where large drafts are made on ground waters by pumping they must be replenished from time to time or the total available supply will soon be exhausted. This addition to the ground water may be made by local rainfall or by underground percolation from other areas. At Enid the sands that contain the water are underlain by nearly impervious red shale, along whose surface the ground water moves. The drainage of the region shows that the red-bed surface slopes away from Enid in all directions except toward the northwest, and consequently that is the only direction from which the Tertiary sands could receive water by percolation from outside areas. Even northwest of the city, however, the Tertiary deposits are considerably dissected, making it improbable that there is much underflow into the Enid area from that direction. Where the soil is a heavy gumbo much of the rain is shed into the streams, but where the soil and subsoil are sandy a large part of the rain percolates to the ground-water level. Much of the Enid area is practically level and the soil is on the whole absorptive enough to prevent much run-off, so that the local rainfall is without question the chief factor in replenishing the ground-water supply of the Tertiary sands and gravels.

The well waters from the Tertiary deposits are generally of good quality. An analysis of water from one of the test wells put down by the city is given below. The analysis originally reported in hypothetical combinations in grams per gallon has been converted into ionic form in parts per million.

Analysis of water from a test well at the waterworks, Enid, Okla.

[Parts per million.]

Calcium (Ca)	82
Magnesium (Mg)	27
Sodium and potassium (Na+K)	41
Bicarbonate radicle (HCO_3)	320
Sulphate radicle (SO_4)	58
Chlorine (Cl)	56
Total dissolved solids	418

This analysis represents a moderately mineralized calcium-carbonate water. The hardness of the water, about 320 parts per million, is rather high, and such a supply would have to be "broken" or softened for use in laundry work. It carries about 300 parts per million of scale-forming matter but probably would not cause foaming or be corrosive in boilers. It is satisfactory for irrigation.

IRRIGATION.

To be readily irrigable land must be nearly level and its surface must be comparatively smooth. Many of the minor irregularities can be removed by grading, but where there are numerous large gullies and the broader undulations of the ground are too pronounced the cost of leveling would be prohibitive. Around Enid some large tracts could be prepared for irrigation at small cost and some parts of almost any farm are irrigable.

The success of an irrigation project in this vicinity depends largely on the cost of pumping. This expense is more complex than it seems and includes items that are too often neglected in making estimates of the cost of pumping. Besides the actual operating expenses, which include attendance, repairs, and the cost of power, it includes several fixed charges, such as interest on the investment and depreciation. The fixed charges go on whether the plant is running or not, but the operating expenses are incurred only while the plant is in actual use. The cost of power, which is ordinarily the largest item of the running expenses, is proportional to the depth from which water must be pumped, and beyond certain limits of depth it does not pay to pump water. These limits vary in different regions, depending chiefly on the cost of power and the value of the crops. In some regions, as in the orange country of southern California, it pays to pump water from depths which would be out of question in less favored regions.

In the Enid area the cost of developing and pumping water from the "Red Beds" will be much greater than the cost of developing and pumping from the Tertiary or younger sands and gravels.

The results of the pumping tests at Oklahoma City show that the yield from individual wells in the "Red Beds" is not large, the most

productive well of the group yielding only 1.8 gallons of water per foot of drawdown. The cost for power increases with every additional foot of drawdown, so that to avoid pumping from depths beyond the economical limit and still get an irrigating stream large enough to cover the ground quickly and evenly, means of storage would have to be provided. Earth reservoirs built out of the "red keel" of this region would be well suited for this purpose. An efficient pumping system, to furnish even a moderate amount of water under these conditions, would be expensive, so that the interest on the initial cost of the plant and depreciation added to the cost of power for pumping from deep wells makes the final cost per acre-foot of water pumped so high that the use of water from the "Red Beds" should not be recommended unless no other supply is available, and then only for certain intensive crops, such as fruit or garden truck, where the financial return per acre would warrant a heavy expense for pumping.

On the other hand, the water in the Tertiary and alluvial deposits, represented by the shaded area on the accompanying map (Pl. I), is easily obtained at a low cost for pumping almost anywhere in this area in quantities sufficient for irrigation. The supply from the Tertiary and alluvial deposits is by no means inexhaustible, but moderate drafts on the supply during the comparatively short season in which irrigation is necessary will be compensated by local rainfall throughout the year.

In the Tertiary deposits and in the later alluvial deposits along some of the streams the water is so near the surface that a group of wells could be operated from a single pumping plant. Either driven or bored wells connected to a common suction main could be used. Such a system is very flexible and the extent to which it can be enlarged by adding new wells as the requirements demand is limited only by the capacity of the pumps.

As the water-bearing material underlying the Enid area is mostly sand and few of the wells show gravel, it is thought that a certain type of well, which has been called the "gravel-wall well" and which has been successfully used in other regions, would be suitable here. In wells of this type the perforated casing or screen is surrounded by a thick shell of gravel or crushed rock, which separates it from the surrounding water-bearing sand. The method of construction is as follows: A large casing is first sunk from the surface of the ground into the water-bearing sand; sand is then removed through this casing with a sand bucket or a centrifugal pump; as material is removed from the bottom more caves in from the sides until a large cavity is formed; a smaller casing with many large perforations or fitted with a coarse screen is then let down inside of the

first casing to the bottom of the cavity, and clean gravel or crushed rock is dumped down the intervening space between the outer and inner casings until the cavity is filled. The outer casing may then be pulled up to the top of the water-bearing sand or pulled out entirely and used over again for some other well. The advantage of a well of this kind over the ordinary bored well lies in the fact that a much coarser screen can be used on the casing than would ordinarily be possible where the water occurs in sand.

A well involving these principles has been successfully used for a number of years on the farm of Charles King, in the SW. ¼ sec. 11, Garland Township. Being the only irrigating pumping plant in this region worthy of mention, it warrants a brief description. The well consists of a circular pump pit extending to the water level 22 feet below the surface, with a 24-inch perforated casing sunk to the "red keel" and surrounded by a shell of gravel. A 3½-inch Gould centrifugal pump, capable of delivering about 300 gallons a minute and belted to an 8-horsepower Fairbanks-Morse gasoline engine, is set in the pit at water level. Mr. King irrigates 15 acres of apple orchard in addition to several acres of small fruits and general garden truck. The centers between the rows are flooded and for the orchard four waterings a season are found to be sufficient. Each watering requires four or five days with the pump running 18 hours a day.

The investment in the pumping plant has been found to be very profitable, because irrigation greatly increases the yield from the trees in normal years and prevents crop failure in years of drought. Mr. King estimates the total cost of the plant, including the well, at $500. In this case the engine was bought second hand, and the cost of labor for digging the well and installing the machinery was probably not taken into account, so that the ordinary cost of plants of this kind would be considerably more.

The available supply of water in the Tertiary and later alluvial sands and gravels in the Enid region is probably not sufficient for the heavy irrigation of large tracts but is large enough for the irrigation of many small tracts distributed over the area. The raising of irrigated crops in connection with the regular field crops should be encouraged, as it will help to tide the farmer over financial crises when the ordinary crops fail. Alfalfa and certain kinds of fruits and vegetables do well in the region around Enid, and if the ground water which is available is used conservatively and intelligently for the irrigation of these and perhaps some other crops it can be made to add greatly to the wealth of the community.

Records of typical wells in the vicinity of Enid, Garfield County, Okla.

No.[a]	Location. Township.	Section.	Quarter.	Owner.	Kind of well.	Depth of well.	Depth to water level.	Geologic source of water.	Yield.[b]	Log (thickness of strata in feet).[c]
						Feet.	*Feet.*			
1	Keowee	20	SW.	H. D. Lacy		18	13	Carboniferous "Red Beds."	2/3 gallon a minute	
2	Kremlin	23	NW.	George Grim	Bored	40		do	Domestic supply[b]	Clay, 16; "keel,"[c] 24.
3	Hobart	15	NW.	P. C. Murphy	do	50	40	Tertiary or later	do	Clay, 40; sand and gravel, 10.
4	do	17	NE.	C. M. Dyche	do	50	40	do	do	Clay, 40; coarse sand, 10.
7	Banner	8	SE.	C. Arnold	do	60	46	do	do	Clay, 46; coarse sand, 14.
8	do	9	SE.	C. Porter	do	62	42	do	do	Clay, 42; sand and gravel, 19 or 20.
9	do	30	SW.	C. Miller	do	112		do	do	
10	do	33	SW.	A. F. Baade	do	40	30	do	do	Clay, 30; sand, 10.
13	North Enid	29	NW.	City of Enid	do	2,200	Fresh water at 20; salt water at 2,145.	Tertiary and "Red Beds."		Soil, 20; coarse sand, 28; "keel," 2,097; "limestone," 30.
14	do	29	SE.	Chicago, Rock Island & Pacific Ry.	1 dug well and several driven wells.	30	12	Tertiary or later	5,000 gallons an hour.	
15	do	27	NW.	Goltry & Sons	Bored	50	40	do	Domestic supply	Clay, 40; sand and gravel, 10.
16	do	33	SE.	State Feeble-minded Institute.	do	45	36	do	do	Clay, 36; sand and gravel, 9.
17	Union	19	SE.	S. M. Hayden	do	48	40	do	do	Clay, 40; coarse sand, 8.
18	do	25	SW.	E. McFarland	do	38	30	do	do	Clay, 30; coarse sand, 8.
19	do	28	SE.	St. Louis & San Francisco R. R.	Dug	42	30	do	2,000 gallons an hour.	"Gumbo," 30; sand, 6.
20	do	30	NW.	A. J. Hopwood	Bored	45	35	do	Domestic supply	Clay, 35; sand and gravel, 10.
21	do	35	NW.	School	do	33	25	do	do	Clay, 25; sand and gravel, 8.
22	Patterson	19	NW.	R. K. Wilson	do		Artesian at times	Carboniferous "Red Beds."	do	
23	do	31	SW.	R. W. Miller	do		do	do	do	
24	Enid	5	SW.	Atchison, Topeka & Santa Fe Ry.	Dug			Tertiary or later	Water for locomotives.	
25	do	6	SW.	St. Louis & San Francisco R. R.	Driven (several wells).	43	34	do	83,000 gallons a day.	Soil, 2–3; pack sand, 18; fine clean sand, 12–18; coarse sand and gravel, 5–11.
26	do	7	NE.	Arctic Ice & Refrigerating Co.	Driven (60 wells)	46	18	do	200 gallons a minute.	Sandy clay, 18; fine sand, 10; coarse sand, 10.
27	do	7	SE.	Enid Gas & Electric Co.	Driven (5 wells)	15	6–7	do	60,000 gallons a day.	

[a] Numbers refer to well numbers on map.
[b] "Domestic supply" as here used means sufficient for ordinary house and farm use.
[c] "Keel" is the local name for Carboniferous "Red Beds."

Records of typical wells in the vicinity of Enid, Garfield County, Okla.—Continued.

No.	Location. Township.	Location. Section.	Location. Quarter.	Owner.	Kind of well.	Depth of well.	Depth to water level.	Geologic source of water.	Yield.	Log (thickness of strata in feet).
						Feet.	*Feet.*			
28	Enid	18	NE.	Enid Mill & Elevator Co.	Dug	47½	37	Tertiary or later		Soil, 37; coarse sand, 3½.
29	do	21	NW.	Ida G. West	Bored	88		Carboniferous "Red Beds."	Domestic supply	Clay, 20; "keel," 68.
32	do	24	SE.	Frank Foster	do	50	Artesian at times	do	do	Clay, 16; "keel," 34.
35	Garland	1	SE.	Enid waterworks	Driven (32 wells)	49–50	31	Tertiary or later	1,500,000 gallons a day.	Clay, 20; fine sand, 5–12; "blue clay," 3–6; coarse clean sand, 15–18.
42	do	7	NE.	School	Bored			do	Domestic supply	Sand, 11; quicksand (?); "keel," 10.
45	do	11	SW.	Chas. King	Dug and bored	43	22	do	300 gallons a minute.	Soil, 5 or 6; yellow clay, 5 or 6, fine sand, 10 or 12; coarse sand, 21.
55	do	27	NE.	School	Bored	36	28	do	Domestic supply	Clay, 28; sand, 8.
66	do	34	SE.	W. M. Story	do	96	45	Carboniferous "Red Beds."	do	Soil, 10; "keel," 86.
76	Logan	14	SE.	Abbie L. Blazer	do	43	35	Tertiary or later	do	Clay, 16; sand, 5; clay, 14; sand, 8.
92	do	25	SW.	W. P. Hodgsen	do	22	18	do	do	
93	do	26	NW.	C. H. Cecil		32	20	do	do	Soil, 20; sand, 12.
106	Waukomis	3	SE.	J. E. Giles	Bored	51		Carboniferous "Red Beds."	do	Clay, 16; "keel," 35.
110	do	15	SW.	R. E. Isbell	do	58	34	do	do	Clay, 34; "keel," 24.
111	do	21	NW.	M. C. Richards	do	50	40	Tertiary or later	do	Black loam, 40; black clay, 10.
112	do	24	SW.	Town of Waukomis.	Dug and bored	62	20	Carboniferous "Red Beds."	Maximum capacity, 90 gallons a minute.	Soil, 5; "keel," 57.
113	do	29	NW.	W. R. Wilson		60	41	do	Domestic supply	Soil, 18; "rock," 42.
115	Hackberry	1	SE.	J. A. Henry	Bored	40	Water rises 3½ feet above ground.	do	8 gallons a minute.	Soil, 17; "keel," 23.
116	do	20	NW.	J. A. Dodson			10	do	Domestic supply	

NOTE ON GROUND WATER FOR IRRIGATION ON THE GREAT PLAINS.

By O. E. Meinzer.

The agricultural utilization of the vast area of Great Plains, with their fertile land but irregular rainfall, has long constituted a large and perplexing problem, and in spite of all the investigation and experimentation that have been bestowed on this great region in the last few decades the problem is still largely unsolved. Series of wet years arouse the inhabitants to great optimism and lead to much apparent progress, but they are invariably followed by series of dry years that still have disastrous effects. No methods of agriculture have yet been developed that satisfactorily solve the problem, and there is still great need for irrigation. Even as far east as Enid, Okla., where the annual precipitation averages more than 30 inches, crops often suffer severely for want of water. Agriculture on the Great Plains will never be fully developed until all the available ground water is recovered and used in irrigation.

There are two important sources of ground water on the Great Plains—the Dakota sandstone and the sands and gravels of late Tertiary and Quaternary age. In extensive areas in South Dakota, in the Arkansas Valley of Colorado, and in some other places the Dakota sandstone yields large quantities of artesian water, but over much of the southern part of the Great Plains this sandstone is absent and the Tertiary deposits rest on the Carboniferous "Red Beds," which are unpromising as a source of water for irrigation. The largest supply of water is found in the Tertiary and Quaternary sands and gravels that lie near the surface over an area of more than 100,000 square miles of valley and plain in eastern Colorado and New Mexico and in western Nebraska, Kansas, Oklahoma, and Texas. These beds do not as a rule yield flows. Ordinarily the water must be recovered by pumping. Pumping plants have been installed at some places, chiefly in the Arkansas Valley and in certain shallow-water belts in western Texas and adjacent parts of New Mexico, but many more can be successfully operated. The solution of the problem of irrigation with water pumped from the Tertiary and Quaternary sands and gravels depends on (1) the cost of recovering the water and its value in producing crops and (2) the quantity of water available.

Irrigation with pumped well water is always expensive, for to the cost of the ditches, of the land grading, and of applying the water must be added the cost of the wells, pumps, engines, connections, and pump house, of the fuel and lubricating oil, of the labor required in operating the plant, and of repairs and renewals for different parts of the plant from time to time.

The cost of pumping a given quantity of water depends on the yield of the wells and the depth from which the water must be lifted, on

the kind of machinery and fuel used, and on other factors. It depends very largely on the adjustment of the pumps and engines to each other and to the work they have to do and on the working condition of all parts of the plant. Obviously pumping for irrigation is feasible only where ground water is readily available, where the equipment is suitable and is intelligently managed, and where the water is put to good use through wise agricultural practice.

Because of improvements in pumping machinery—especially in internal-combustion engines—water can be pumped at less cost now than formerly, and because of improved methods of irrigation and agriculture and better adaptation of crops to water supply the value of pumped water has been increased. Hence pumping for irrigation is practicable to-day in localities where it was not practicable 10 or 20 years ago. Moreover, progress in ground-water irrigation on the Great Plains must depend largely on mechanical improvements in pumping machinery and better adaptation of crops and cultural methods to this kind of water supply. With good management pumping for irrigation is now generally feasible where the water level stands within 25 or perhaps 50 feet of the surface and for the irrigation of vegetables and fruit where the depth to water is even greater.

There has been much speculation as to the quantity of water that the Tertiary and Quaternary deposits of the Great Plains will yield, but little definite information on the subject has been obtained. On account of this general lack of knowledge there has been wide divergence of opinion, some persons assuming that the supply is inadequate for any considerable amount of irrigation and others assuming, quite as unwisely, that the supply is inexhaustible. A thorough investigation is needed of the annual accretions to and discharges from these deposits in order that an estimate may be made of the quantity of water that is annually available for irrigation.

The fact is well established that the supply does not come chiefly from the mountains, as is still popularly believed, but from the rain and snow that fall on the Great Plains. Where the soil is underlain by thick lime hardpan comparatively little of the rain reaches the ground water, but in the sandy areas percolation is greater. The fact that the source of supply is local is not unfavorable, as is supposed by many persons, but rather means that the intake area is extensive and that therefore the total supply is large, even though only a small part of the precipitation percolates to the ground-water level. If only 2 or 3 per cent of the precipitation on the Great Plains joins the ground water the supply is sufficient for the annual irrigation of a million acres.

The water in any particular part of the region, however, must be used in that part and is not available for use in some distant area. The supply that can be utilized in any locality is thus limited, and the

development of the entire region to its maximum capacity requires that the pumping plants be widely distributed over the shallow-water areas.

Wherever in the semiarid parts of the Great Plains the ground water is near the surface, the soil good, and the yield of wells fairly copious, pumping plants for irrigation should be installed. In some areas a single well may yield several hundred gallons a minute; in other areas a group of wells may be required to produce this amount of water. A plant yielding 100 gallons a minute will irrigate 10 acres or more. If in any locality the ground-water conditions are found to be favorable and a number of pumping plants have been successfully operated for some time, it may be desirable to consider the installation, for economy and convenience, of a central power plant with electric transmission lines leading to the individual pumping plants. On account of the irregularity of the sand and gravel deposits, however, no central power plant should be installed until the water supply for which it is intended has been fully tested by many wells. Moreover, on account of the lack of knowledge as to the rate at which the ground water is renewed great caution should obviously be exercised in installing expensive power plants.

The Tertiary deposits in the vicinity of Enid, Okla., described by Mr. Schwennesen, form a small and nearly detached part of the widespread Tertiary water-bearing formation of the Great Plains and illustrate most of the statements that have been made in regard to the Great Plains in general. Thus, Mr. Schwennesen's investigation shows that the water supply in these deposits is derived chiefly by the percolation of the rain which falls in the vicinity, that although this supply is not large it is to some extent replenished by every heavy rainstorm, and that if it is withdrawn in moderate quantities for irrigation it will add materially to the agricultural production of the community. This investigation also shows the wisdom of thoroughly testing irrigation on a small scale before making heavy expenditures for large power plants.

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